Evaluation of user-oriented attractiveness of imaging spectroscopy data using the value-benefit analysis (VBA)

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Abstract: While there is a strong need for hyperspectral imagery, the user-driven requirements are not well defined in view of defined protocols for calibration, acquisition, processing and in-situ measurements in compliance with existing standards. Therefore an analysis was performed in the frame of the EC project HYRESSA, regarding the question “What are the individual user requirements on hyperspectral imagery and the related data products?”. For this analysis a questionnaire and a subsequent benefit-value analysis helped to retrieve users needs and evaluate open items accordingly. Following the methodology of the Value-Benefit Analysis (VBA), the answer can be described in hierarchical ordered multidimensional objective model. The VBA serves as well-known tool for systematic problem solving process as a possibility of comparing projects or solutions. It enables the evaluation on the basis of a multidimensional objective model and can be extended by expert’s preferences. Therefore the scaling method (Law of Comparative Judgment) was applied for receiving the desired ranking judgments. The result, which is the relative value of projects concerning a well-defined main objective can now be produced analytically. The investigation showed − besides details on user needs − that a VBA is a suitable method to analyse needs of hyperspectral data and to support sensor/data specification-building process. The VBA has the advantage, to be easy and clear to handle, resulting in a comprehensive evaluation. The disadvantage are the necessary efforts and the partly non-availability of all sensor data parameters. The paper summarizes all results of the analysis and gives insight to VBA methodology, statistics and others more.

EVALUATION OF USER-ORIENTED ATTRACTIVENESS OF IMAGING SPECTROSCOPY DATA USING THE VALUE-BENEFIT ANALYSIS (VBA)

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ABSTRACT

While there is a strong need for hyperspectral imagery, the user-driven requirements are not well defined in view of defined protocols for calibration, acquisition, processing and in-situ measurements in compliance with existing standards. Therefore an analysis was performed in the frame of the EC project HYRESSA, regarding the question "What are the individual user requirements on hyperspectral imagery and the related data products?". For this analysis a questionnaire and a subsequent benefit-value analysis helped to retrieve users needs and evaluate open items accordingly. Following the methodology of the Value-Benefit Analysis (VBA), the answer can be described in hierarchical ordered multidimensional objective model.

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Keywords: HYRESSA, Value-Benefit -Analysis, data products, quality assessment

INTRODUCTION

This investigation was carried out in the frame of the EC project HYRESSA /i,ii/. HYRESSA is investigating the user needs of the European hyperspectral research community with respect to access to and accuracy, quality and conformity of hyperspectral images - especially with the advent of next-generation European hyperspectral sensors in order to refine protocols related to calibration, acquisition, processing and in-situ measurements in compliance with standards. HYRESSA is a starting point to build a European user-oriented hyperspectral remote sensing Research Infrastructure. For more information, the project created its own web site, where relevant information and news about follow-on activities can be gathered: www.hyressa.net

In the frame of the HYRESSA project an analysis is performed regarding the question "What are your individual user requirements for hyperspectral imagery and related data products?" While there is a strong need for hyperspectral imagery, the user-driven requirements are not well defined in terms of protocols in compliance with existing standards. The QUN answered by the researchers allowed the assessment of users needs and the evaluation of these needs through comparison with data provision.

Within this project a Questionnaire of User Needs (QUN) was created in collaboration with VITO and the HYRESSA Team as paper-based and web-based versions. After requesting its completion by the user community of researchers in the field of imaging spectroscopy, the results were analysed to yield important information about the required hyperspectral data quality, products and future trends.
In the following the methodology and the main results retrieved from Value-Benefit Analysis (VBA) are summarized.

VALUE-BENEFIT ANALYSIS (VBA) METHODOLOGY

The Value-Benefit Analysis (VBA) is a well-known tool /iii/ for systematic problem solving process as a possibility of comparing projects or solutions. It enables the evaluation on the basis of a multi-dimensional objective model and can be extended by expert's preferences. Therefore the scaling method (Law of Comparative Judgment) was applied for receiving the desired ranking judgments. The VBA is a method for an appropriate evaluation of complex project alternatives on the basis of a multidimensional objective system. In practice, it is used when the objectives relevant for the evaluation of alternatives cannot be measured solely in monetary units, which is the case particularly for capital-intensive projects in economics, politics and research. The theory of a value-benefit analysis has first been described in detail by C. Zangemeister in 1973.
In the following, the approach is explained in order to create an objective model to describe the "Maximal attractiveness of hyperspectral data". The analysis steps are relatively simple and consist of an objective model (incl. specific value indicators), which serves as the questionnaire (the QUN) for the HSI user and the describer of the HSI data.
1. Compilation of a multi-dimensional objective model
The first step is to define a main objective of the ***objective model***, i.e., "Maximum attractiveness of hyper-spectral data". Thereafter all properties of hyperspectral image data (VNIR-TIR) must be arrayed and sorted. Therefore a tree diagram is used, which leads to a hierarchical structure of the objective model. On top of the diagram the main objective is placed which is branched (and further subdivided) to three subordinated objective levels. At the lowest level of the objective model are the objective value indicators and dedicated value indicator functions. These indicators are e.g., swath width, processing steps, radiometric accuracy, price etc. and in general can be quantified in specific units, e.g., km, level 1-3, %, and €/km^2.
2. Evaluation of objective model by experts / users
The evaluation step consists of an objective model weighting procedure of experts (i.e., the user filling out the QUN). A weighting of the objective model is needed since the objectives have different relative values for different user preferences. The participating users are split up into different application areas. This first evaluation process is realised by users (also potential users) in the field of remote sensing. The weighting is performed in distributing 100 percent points on the objectives to each branching point in each objective level. These branching weights denote the relative objective value concerning the main objective on top of the tree diagram. The result is an objective model, where all objective levels and objective value functions are weighted hierarchically with relative weights (priorities) concerning the objective-specific value of hyperspectral imaging data. Additionally, absolute values for the indicators can be specified by the user, for example the spectral resolution [in nm] which the user prefers. These ***objective values*** are needed for step #4 of the VBA.
3. Hyperspectral imager survey (VNIR-TIR)
In this step the alternative sensor data are described using the lowest level of the objective model, the value indicators. The sensor makers or the data-distributing agencies provide the relevant information and the relevant value indicators can be determined for each HSI data delivery scheme.
4. Synthesis of values for each sensor
In a final step, the determination of the relative values of each sensor is achieved by the synthesis of values. First the relative values of each tree level are multiplied following a specific tree branch to get the final relative values for a specific indicator. Then the absolute user and sensor values are compared. In case the sensor value fulfils the user requirements, the full relative user value is used for the evaluation. By limited fulfilments of x %, only x % of the relative value is further

brought to the evaluation. Finally, all resulting relative values are summed up and a percentage results, indicating how good the main objective “Maximum attractiveness of hyperspectral data” is achieved for a given sensor and a specific application. The result is called ***objective return***.
In the following diagram the basic VBA approach applied within the HYRESSA project can be depicted.

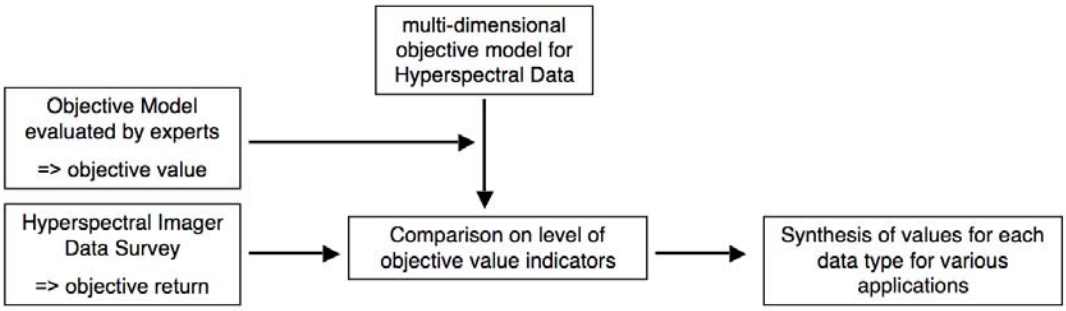

Figure 1: The methodology of Value-benefit analysis (VBA) applied on hyperspectral data.

OBJECTIVE MODEL, VALUE AND RETURN

As the requirements for hyperspectral data depend strongly on the application area, the participating users were divided into self-selected application areas. During the first HYRESSA Progress Meeting the following application groups were selected:
Vegetation (in general), e.g., detection of chlorophyll, cellulose,
Forestry, vegetation, but with possible differences concerning spatial resolution,
Agriculture, as vegetation, but with possible differences concerning spatial resolution
Atmosphere, e.g., detection of aerosols and trace gases,
Land Use, e.g., detection of land cover and change,
Geology/Mining, e.g., detection of minerals, soil types,
Limnology/Coastal waters, e.g., detection of plankton, dissolved organic material, sediment content.

1) OBJECTIVE MODEL

In order to set-up an objective model, a tree model was defined (see ***Figure 2***). The main objective is divided into four different sub-objectives on the 2nd objective level, i.e., best image based properties (A), best ergonomic properties (B), lowest costs (C), and best services (D).
The objectives of the 2nd objective level are further hierarchically divided into sub-objectives on the 3rd objective level. As a result, objective A is subdivided into best spectral, best geometric, best radiometric and best temporal parameters. The objective B leads to best data delivery and best documentation. The objective C results in lowest data costs and lowest further expenses and objective D is hierarchically split into best support of data provider and best further services.
The same approach is taken for the 4th objective level, which also includes the objective indicator values. The first two objective levels of the model are presented in, the sub-objectives of A, B, C and D.

2) OBJECTIVE VALUE

A total of over 74 researchers filled out the objective model. The respondents can be structured according to their background in the following way: 47 % University, 38 % Research Institute and 15 % Government. Most of the respondents were very experienced users and who have worked with hyperspectral data from several sensors. The origin of the researchers is shown in ***Table 1*** demonstrating that opinions from the majority of the countries in the European Union were obtained. It may also give some indication of interests within the Community on the HYRESSA project and/or on the subject of HSI itself.

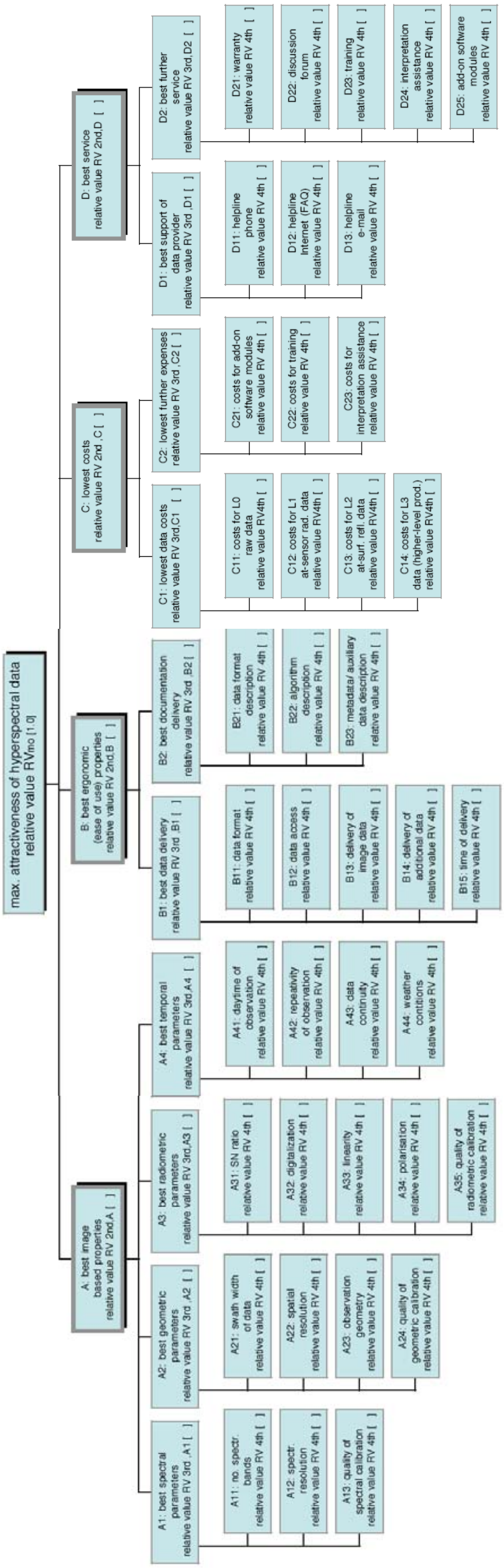

Figure 2: Objective model for hyperspectral (satellite and airborne) imagers.

Table 1: Researchers' country of origin (left) and Key-application areas of researchers (right)

Country of Origin	Number of Replies
Belgium	14
Czech Republic	2
Estonia	1
Finland	2
France	4
Germany	13
Great Britain	5
Italy	2
Netherlands	9
Norway	3
Poland	4
Slovakia	1
Spain	5
Switzerland	9

Application area	Number of Replies
Atmosphere	3
Limnology /Coastal Waters	10
Geology and Landuse	19
Vegetation (incl. Agriculture and Forestry)	42

Table 1 shows how the 74 QUN-responses were distributed into the different application areas. The distribution may reflect the research interests in hyperspectral remote sensing in Europe, i.e., research seems mainly focused on vegetation issues. However, since for some of application areas (especially atmosphere), only a small number of responses were generated, statically relevant conclusions are difficult to make.
For the VBA, the average of the resulting relative values for each application was calculated and statistically analysed.

3) OBJECTIVE RETURN

For the objective return, a survey on Earth observation hyperspectral data was performed covering the most prominent spaceborne (HYPERION, CHRIS) and airborne (APEX, AHS, ARES, HYSPEX, CASI, AISA) sensors. Therefore, sensor makers and the data-distributing agencies were contacted for providing the relevant information. At the end, for all alternative HSI data and each HSI data delivery scheme, the value indicators could be filled described the objective model on the highest level of detail.
There exists a relative high number of hyperspectral imagers, for which data was provided to a public and civil European research community. Therefore it was selected to cover the most frequent high spatial resolution HSI data providers for spaceborne and airborne imager data.
The data from these sensors were described using the lowest level of the objective model, the value indicators. The survey was carried out using internet research and direct information from the sensor operators.

RESULTS

Results of the VBA can be described as relative or absolute values. Whereas the relative values are describing the relative importance of a sensor or a value indicator to fulfil the overall objective, absolute values become clear requirements, being benchmarks from where a certain objective can be regarded to be fulfilled.

1) RELATIVE VALUES

In this section the relative value for each sensor and each application related to the main objective is shown. With other words, it is possible to quantify directly the attractiveness of the sensor data for a specific application. This attractiveness is related to given objective return and objective

evaluation and the subsequent synthesis of the values, i.e., fully traceable and comparable on all levels of the objective tree.
Table 2 shows the resulting percentage, how good the main objective "Maximum attractiveness of hyperspectral data" is achieved for a given sensor and a specific application. First of all it stands out that the results for a specific sensor do not change strongly from application to application. The range lies between 5 and 12 % for all sensors.

Table 2: Resulting overall relative values for different sensors and applications.

	Atmosphere[1]	Geology	Landuse	Limnology	Vegetation	Mean
AHS	0.62	0.68	0.66	0.66	0.70	0.66
AISA (DUAL)	0.56	0.55	0.54	0.55	0.56	0.55
APEX	0.70	0.74	0.72	0.78	0.76	0.74
ARES	0.67	0.75	0.72	0.74	0.75	0.73
AVIRIS	0.57	0.62	0.59	0.61	0.62	0.60
CASI	0.58	0.60	0.57	0.59	0.60	0.59
CHRIS	0.70	0.71	0.72	0.74	0.72	0.72
HYPERION	0.75	0.77	0.78	0.78	0.78	0.78
HYSPEX	0.69	0.72	0.68	0.72	0.72	0.71

The spaceborne sensor HYPERION is receiving the highest relative values for all applications, followed by the airborne sensors APEX, ARES, HYSPEX and the spaceborne sensor CHRIS assuming that all applications are equally important. This result may surprise and need to be explained in more detail.

Therefore it was needed to take a view in the objective tree and analyse the relative sensor values within the 2nd objective level, where a separation was done between the Image-based Properties (A), Best ergonomic Properties (B), Lowest Costs (C) and Best Service (D). As it is not possible to depict the table for every application, the one with the most filled out QUNs is chosen as example: vegetation.

Table 3: Relative values for different sensors and application vegetation for the 2nd objective level with A: image based properties. B: ergonomic properties. C: lowest costs. D: best service.

	A	B	C	D	Total
AHS	0.23	0.19	0.15	0.13	0.70
AISA - DUAL	0.19	0.10	0.15	0.13	0.56
APEX	0.22	0.21	0.15	0.18	0.76
ARES	0.23	0.20	0.15	0.17	0.75
AVIRIS	0.22	0.17	0.15	0.09	0.62
CASI	0.17	0.16	0.15	0.13	0.60
CHRIS	0.17	0.16	0.23	0.16	0.72
HYPERION	0.20	0.19	0.23	0.16	0.78
HYSPEX	0.22	0.21	0.15	0.15	0.72

HYPERION does not receive the best values in A, B and D, but an explicit better value for C (lowest costs) is sufficient to obtain the best value in total. The costs are so important for the user, that the comparable low SNR of HYPERION is not critical for an overall assessment of the sensor.

[1] Within the atmospheric group the absolute values differed very much, depending on the subject of research: global – urban, aerosol – trace gases.

Note, that the specific values are the result of the user assessment giving the Image-based Properties A lower priority.
The performance of the second spaceborne sensor CHRIS is slightly lower, although its data is even available for free for research projects. Here the underperformance in A and B are significant due to the limitation of the sensor to the VNIR region. As already shown earlier (see ***Figure 3***) the average user requires a sensor with bands in the VNIR and SWIR region. This is also why the CASI-3 receives less value, when compared with data from sensors covering the entire VNIR-SWIR spectral range.
AHS and ARES get slightly better values (0.23) for the Image-based Properties (A) than APEX and HYSPEX (0.22). This originates in the additional spectral region that the two sensors cover, the thermal infrared. ***Table 3*** also shows that ARES is performing better than APEX for geology applications, since the thermal infrared is very important for geological research, but less important for other applications.
AVIRIS has less relative importance for the user community in Europe, particularly due to the fact, that the sensor has rarely made the step over the Atlantic. AISA shows the poorest results of all airborne sensors in A, because of the inferior spectral calibration (accuracies of 2-6 nm) and looses points in the ergonomic properties as no Level 2 and 3 data is available and additional data is hardly provided.

2) ABSOLUTE VALUES

An overview about absolute values retrieved from the VBA is given in ***Table 4***. These values reflect the user requirements in all possible dimensions of the data.
The demanded number of spectral bands ranges from 200 to 3000 over the entire spectral region (VNIR-TIR). Whereas Agriculture, Limnology, Land-use and Vegetation users are satisfied with 200 to 300 bands, the geological, atmospheric and some vegetation applications explicitly need more spectral bands. Unfortunately, for the atmospheric applications, the absolute values differed very much, and due to the fact that the number of experts was very limited the values represent just the mean out of the given figures. After discussion with experts in the atmospheric group, the observation requirements heavily depend on the observation target (reaching from some spectral bands for aerosol studies to a huge number of bands for trace gas retrieval) and purpose (spatially coarse resolution for global, and high for urban observation). Here definitely more research is needed.
The required spectral resolution in the VNIR ranges from 0.05 to 30 nm, in the SWIR from 0.2 to 40 nm and in the MIR/TIR from 4 to 400 nm. Figure 11 shows the required spectral resolution for different applications. The high spectral resolution for the application geology is significant different to the other applications, especially in the MIR/TIR range. The spatial resolution is expected to be between 4 and 20 meters in the VNIR and SWIR and between 10 and 30 meters in the MIR and TIR for all applications but atmosphere. The requirements for vegetation, and geology are very similar, asking for a SNR of 400-500 in the VNIR, in contrast limnological and atmospheric applications need higher SNR of 700 and 1500.

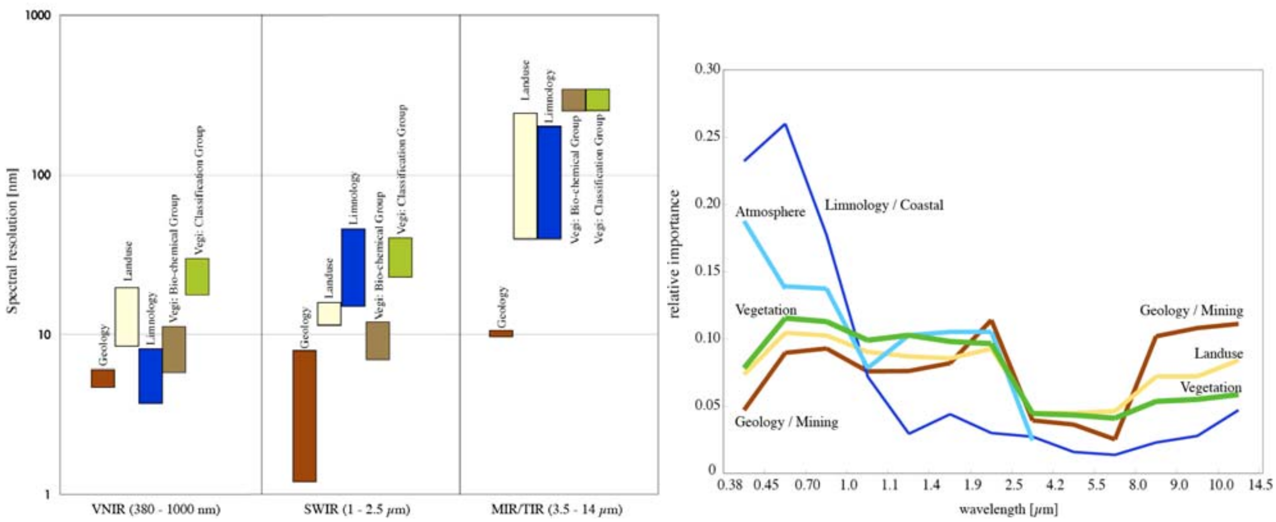

Figure 3: Spectral resolution vs. spectral range (left) and relative importance of spectral ranges (right).

SUMMARY AND CONCLUSION

Since these first steps of hyperspectral imaging (HSI) over 30 years ago, both, developed HSI applications and technology demonstrated its high potentials. Today, HSI research is indispensable and strongly needed for many different applications. However, it became clear, that still important steps have to be undertaken in order to receive standardized products, fully traceable uncertainties and operational data acquisition. These steps are urgently needed to account appropriately for the complex interaction between solar and Earth radiation and surface structures leading to a better definition of related models for climate, hydrodynamics and ecology.

In order to better understand the way-to-go in near future, especially when focussing on HSI infrastructure and data delivery, the HYRESSA team was established within the EC (FP6-2004-Infrastructures-6, Contract Number 026194) to analyse the European HSI user request. Within this project a Questionnaire of User Needs (QUN) was created in collaboration with VITO and the HYRESSA Team and distributed within a user community actively interested in HSI research. 74 individual researchers from 14 European countries provided relevant and important input by answering detailed questions about current HSI data and giving an appropriate assessment for future HSI development steps. In order to analyse the data, the Value-Benefit Analysis (VBA) was applied to achieve answers, which are highly transparent and interpretable.

Without doubt, the data from all investigated sensors provide an important contribution for the research community. The current state-of-the-art of HSI data is far beyond the first development steps about 30 years ago. Technology, i.e., instruments, processing schemes and calibration, improved significantly and on the application side the importance of the HSI data contribution for many different research areas, such as climate, eco- and hydrological modelling was demonstrated many times.
However, there are specific user requirements, which are essential to know, since the main objective of this evaluation is to increase the attractiveness of HSI data. Concluding, the HYRESSA QUN Evaluation report provides the following answers:
Better service and reduced costs are very important criteria for the users, resulting in the fact that almost 50% of the data attractiveness is not related to the data itself, but to costs and services!
HSI data providers need to improve their services by considering to establish helplines, workshops, courses or disseminating special add-on software modules etc.,
Pricing policies of HSI data must be decently elaborated within a future European HSI infrastructure, since the user community is not able to cover flight campaign costs on a frequent basis. Here

the establishment of trans-national group-shoots organized within the HSI infrastructure might lead to a solution,
HSI users have very individual preferences, how HSI data should be structured and distributed in order to apply the data for the specific research. This directly leads to sensors requirements for a specific application group (e.g., atmospheric research), or to super-sensors, which are accounting for all application groups equally. A comparison of some specific preferences is given in ***Table 4***.
As a result of the analysis, the HYRESSA team is able to define the requirements for HSI data and its EU infrastructure using the provided evaluation of the European HSI user community.

Table 4: User requirements as result of the VBA.

	Atmosphere[2]	Geology	Land-use	Limnology	Vegetation[3] Group-1 Group-2
No. of bands in total (VNIR-TIR)	3000	300	200	200	200 100
Spectral resolution VNIR [nm]	0.05 - 0.5	6-10	8 - 15	4 - 8	6 - 12 15 - 30
Spectral resolution SWIR [nm]	0.2 - 0.5	2 - 8	10 - 12	10 - 40	8 – 12 25 - 40
Spectral resolution MIR/TIR [nm]	NA	10	40 - 220	40 - 200	300
Spatial resolution VNIR/SWIR [m]	2500	5	4	5 - 20	4 - 5 10 - 30
Spatial resolution MIR/TIR [m]	NA	20 - 30	15	10 - 15	15 30
Swath width VNIR/SWIR [km]	1200	15 - 30	15	25 - 30	20 70
Swath width MIR/TIR [km]	0	15	15 - 20	30 - 40	20 200
SNR VNIR	1500	400	400	700	450
Preferred observation repetition rate	daily-weekly	yearly	monthly-yearly	daily-weekly	weekly-yearly
Preferred data product?	Level 1	Level 1-2	Level 1-2	Level 2	Level 1-2
Preferred observation time?	mid day	mid day or night	daytime	mid day	mid day
What implies an improved service?	add-on SW	add-on SW	add-on SW	add-on SW	add-on SW
Preferred data delivery time?	day-week	month	week	day-week	week

[2] Within the atmospheric group the absolute values differed very much, depending on the subject of research: global – urban, aerosol – trace gases.

[3] Group 1) bio-chemical group, with a main interest in high spectral and spatial resolution, and Group 2) "classification" oriented vegetation group, interested in a relatively broad spectral (< 30 nm) and lower spatial (10-30 m) resolution

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